Practitioner's Docket No. 70470-51

CHAPTER II

Preliminary Classification:

Proposed Class:

Subclass:

TRANSMITTAL LETTER
TO THE UNITED STATES ELECTED OFFICE (EO/US)
(ENTRY INTO U.S. NATIONAL PHASE UNDER CHAPTER II)

DE000/1385	26 April 2000 (26.04.00)	5 June 1999
International Application Number	**International Filing Date**	**International Earliest Priority Date**

TITLE OF INVENTION: VOLTAGE-CONTROLLED OSCILLATOR WITH LC RESONANT CIRCUIT

APPLICANT(S): Herzel, Dr. Frank; Weger, Prof. Dr. Peter

Box PCT
Assistant Commissioner for Patents
Washington D.C. 20231
ATTENTION: EO/US

1. Applicant herewith submits to the United States Elected Office (EO/US) the following items under 35 U.S.C. Section 371:

CERTIFICATION UNDER 37 C.F.R. SECTION 1.10*
(Transmittal Letter to the United States Elected Office (EO/US)--page 1 of 4)
*(Express Mail label number is **mandatory.**)*
(Express Mail certification is optional.)

I hereby certify that this paper, along with any document referred to, is being deposited with the United States Postal Service on this date 3 Dec. 2001, in an envelope as "Express Mail Post Office to Addressee," mailing Label Number EL 829635673US, addressed to the: Assistant Commissioner for Patents, Washington, D.C. 20231.

Stephen L. Grant
(type or print name of person mailing paper)

S L Grant
Signature of person mailing paper

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a. This express request to immediately begin national examination procedures (35 U.S.C. Section 371(f)).

b. The U.S. National Fee (35 U.S.C. Section 371(c)(1)) and other fees (37 C.F.R. Section 1.492) as indicated below:

2. Fees

CLAIMS FEE*	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALC-ULATIONS
	TOTAL CLAIMS	34 -20 =	14	x $18.00 =	$252.00
	INDEPEN-DENT CLAIMS	1 - 3 =	0	x $84.00 =	$0.00
	MULTIPLE DEPENDENT CLAIM(S) (if applicable) + $280.00				$0.00
BASIC FEE	U.S. PTO WAS NOT INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where no international preliminary examination fee as set forth in Section 1.482 has been paid to the U.S. PTO, and payment of an international search fee as set forth in Section 1.445(a)(2) to the U.S. PTO: where a search report on the international application has been prepared by the European Patent Office or the Japanese Patent Office (37 C.F.R. Section 1.492(a)(5)) $890.00				$890.00
	Total of above Calculations				= $1,142.00
SMALL ENTITY	Reduction by 1/2 for filing by small entity, if applicable. Affidavit must be filed. (note 37 CFR Sections 1.9, 1.27, 1.28)				- $0.00
	Subtotal				$1,142.00
	Total National Fee				$1,142.00
	Fee for recording the enclosed assignment document $40.00 (37 C.F.R. Section 1.21(h)). See attached "ASSIGNMENT COVER SHEET".				$40.00
TOTAL	Total Fees enclosed				$1,182.00

*See attached Preliminary Amendment Reducing the Number of Claims.

A check in the amount of $1,182.00 to cover the above fees is enclosed.

3. A copy of the International application as filed (35 U.S.C. Section 371(c)(2)) has been transmitted by the International Bureau.

Date of mailing of the application (from form PCT/IB/308): 14 December 2000

4. A translation of the International application into the English language (35 U.S.C. Section 371(c)(2)) is transmitted herewith.

5. Amendments to the claims of the International application under PCT Article 19 (35 U.S.C. Section 371(c)(3)) have been transmitted by the International Bureau.

6. A translation of the amendments to the claims under PCT Article 19 (38 U.S.C. Section 371(c)(3)) is transmitted herewith.

7. A copy of the international examination report (PCT/IPEA/409) is transmitted herewith.

8. Annex(es) to the international preliminary examination report is/are transmitted herewith.

9. A translation of the annexes to the international preliminary examination report is transmitted herewith.

10. An oath or declaration of the inventor (35 U.S.C. Section 371(c)(4)) complying with 35 U.S.C. Section 115 is submitted herewith, and such oath or declaration identifies the application and any amendments under PCT Article 19 that were transmitted as stated in Section 3 and/or 5; and states that they were reviewed by the inventor as required by 37 C.F.R. Section 1.70.

II. Other document(s) or information included:

11. An International Search Report (PCT/ISA/210) or Declaration under PCT Article 17(2)(a) has been transmitted by the International Bureau.

Date of mailing (from form PCT/IB/308): 23 October 2000.

12. An Information Disclosure Statement under 37 C.F.R. Sections 1.97 and 1.98 is transmitted herewith.

Also transmitted herewith is/are Form PTO-1449 (PTO/SB/08A and 08B) and copies of citations listed.

13. An assignment document is transmitted herewith for recording.

14. Additional documents:

a. Copy of request (PCT/RO/101)

b. International Publication No. 00/76057

Specification, claims and drawing

c. Preliminary amendment (37 C.F.R. Section 1.121)

15. The above items are being transmitted before 30 months from any claimed priority date.

AUTHORIZATION TO CHARGE ADDITIONAL FEES

The Commissioner is hereby authorized to charge the following additional fees that may be required by this paper and during the entire pendency of this application to Account No.: 15-0450

37 C.F.R. Section 1.492(a)(1), (2), (3), and (4) (filing fees)

Date: 3 DEC. 2001

Signature of Practitioner

Reg. No.: 33390
Tel. No.: 330-864-5550
Customer No.: 021324

Stephen L. Grant
Hahn Loeser & Parks LLP
1225 W. Market St.
Akron, OH 44313
USA

Attorney's Docket 7040-51

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Herzel	Examiner:	
Ser. No.:		Art Group:	
Title:	VOLTAGE-CONTROLLED OSCILLATOR WITH LC RESONANT CIRCUIT		
Filed:	3 December 2001	Date:	3 December 2001

PRELIMINARY AMENDMENT

This Preliminary Amendment is filed with the above case, which is the national stage entry in the United States of PCT/DE00/01385. That case is in turn based on German applications 100 21 273.5, which was filed on 26 April 2000 and 199 25 742.6, which was filed on 5 June 1999. The fees for the claims should be calculated based on the claims remaining after the entry of this Preliminary Amendment, which results in 34 total and 1 independent claims. Consistent with the modifications to 37 CFR §1.125, the applicant has provided a substitute specification instead of a clean copy of the paragraphs and claims as they stand after amendment.

Amendments to the Disclosure

The specification as filed has been altered from the literal translation document received to delete information above the title, to insert headings according to US practice, and to insert paragraph numbering in lieu of line numbering. These changes do not introduce new matter.

In addition, please make the following change to the specification:

In the translation of the amended specification, page 1, third paragraph (designated as **[0003]** in the substitute specification:

Japanese patent application [JP] 093 215 38 A describes a voltage-controlled LC-oscillator circuit in which a part of the inductance is short-circuited by means of a switching transistor for given periods of time, whereby the inductive component is reduced at times in such a way that alternate operation of the frequency in two frequency bands is possible.

Amendments to the Claims

After the heading "CLAIMS" and before the beginning of the claims, please insert the words: -- What is claimed is: --

Please amend the claims as follows:

1. (amended) A voltage-controlled oscillator [(VCO)] oscillating at an oscillator frequency comprising :

[-] an LC-resonant circuit with at least one inductor , [(L_1)]

[-] a controllable switching means [(S_v)] which is arranged in the LC-resonant circuit in such a way that it periodically has a conducting and a non-conducting state at the oscillator frequency and has a control input [(V_{con})] connected to a variable dc voltage, the control voltage U_{con} [,] ; and

[-] a further inductor [(L_2)] which can be periodically switched in parallel or in series with the inductor [(L_1)] by way of the switching means [(S_v)] actuated at the oscillator frequency.

2. (amended) The [A] voltage-controlled oscillator of claim 1, further comprising: [(VCO) as set forth in claim 1 characterized in that] a further inductor , [(L_2) can be] periodically connected in parallel or in series with a plurality of inductors [(L_1)] by way of a respective controllable switching means [(S_v)] at the oscillator frequency and the controllable switching means is [(S_v) are] controllable by a variable control voltage U_{con}.

3. (amended) The [A] voltage-controlled oscillator of claim1, wherein: [(VCO) as set forth in claim 1 characterized in that] the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means [(S_v)] within an oscillation period of the oscillator varies, depending [(VCO) is variable in dependence] on the control voltage U_{con}.

4. (amended) The [A] voltage-controlled oscillator of claim 1, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that] the time-averaged effective inductance varies, depending [is variable in dependence] on the control voltage U_{con} according to [in accordance with] the relationship of the duration of the conducting state and

the duration of the non-conducting state of the switching means [(S_v)] within an oscillation period of the oscillator [(VCO)].

5. (amended) The [A] voltage-controlled oscillator of claim1, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that] the controllable switching means comprises [(S_v) are] switching transistors [, in particular MOSFETs].

6. (amended) The [A] voltage-controlled oscillator of claim 17, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that gate terminals (G) of] the MOSFETs have gate terminals that are connected to the control input [(V_{con})] of the control voltage U_{con}.

7. (amended) The [A] voltage-controlled oscillator of claim 6, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that source terminals (S) of] the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

8. (amended) The [A] voltage-controlled oscillator of claim 1, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that] the oscillator [(VCO)] is of a CMOS or bipolar technology.

9. (amended) The [A] voltage-controlled oscillator of claim 1, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that] the oscillator [(VCO)] is used in frequency synthesizers for wide-band systems and for multi-band uses and for clock production and clock recovery in high-speed circuits such as for example microprocessors and memories.

10. (amended) The [A] voltage-controlled oscillator of claim 1, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that in addition to the voltage-controlled inductance] a voltage-controlled capacitance is integrated in the oscillator [(VCO)], which is connected to a tuning voltage U_{tune} by way of a further control input, the tuning input [(V_{tune})].

11. (amended) The [A] voltage-controlled oscillator of claim 10, wherein: [(VCO) as set forth in claim 10 characterized in that] the voltage-controlled capacitance is embodied by means of at least one variable capacitor diode, [in particular by means of two p-MOSFETs (M_1, M_2)], wherein the effective capacitance depends on the tuning voltage U_{tune} at the tuning input [(V_{tune})].

12. (amended) The [A] voltage-controlled oscillator of claim 10, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that] the tuning input [(V_{tune})] of the oscillator [(VCO)] is connected to an output of a phase-locked loop [(PLL)] and the output of the voltage-controlled oscillator [(VCO)] is connected to an input of the phase-locked loop [(PLL)].

13. (amended) The [A] voltage-controlled oscillator of claim 1, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that] the noise of the control voltage at the control input [(V_{con})] is blocked out by means of a high capacitance between the control input [(V_{con})] and ground.

14. (amended) The [A] voltage-controlled oscillator of claim 10, wherein: [(VCO) as set forth in one or more of the preceding claims characterized in that] the tuning input [(V_{tune})] of the voltage-controlled oscillator [(VCO)] is connected to the output of a [the] phase-locked loop [(PLL; PLL1)] and the control input [(V_{con})] of the voltage-controlled oscillator [(VCO)] is connected to an output of a further phase-locked loop [(PLL2)].

Please add the following new claims:

15. (new) The voltage-controlled oscillator of claim 2, wherein:

the time-averaged effective inductance varies, depending on the control voltage U_{con} according to the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means within an oscillation period of the oscillator.

16. (new) The voltage-controlled oscillator of claim 3, wherein:

the time-averaged effective inductance varies, depending on the control voltage U_{con} according to the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means within an oscillation period of the oscillator.

17. (new) The voltage-controlled oscillator of claim 5, wherein:
the switching transistors are MOSFETs.

18. (new) The voltage-controlled oscillator of claim 2, wherein:
the controllable switching means comprises switching transistors.

19. (new) The voltage-controlled oscillator of claim 18, wherein:
the switching transistors are MOSFETs.

20. (new) The voltage-controlled oscillator of claim 3, wherein:
the controllable switching means comprises switching transistors.

21. (new) The voltage-controlled oscillator of claim 20, wherein:
the switching transistors are MOSFETs.

22. (new) The voltage-controlled oscillator of claim 4, wherein:
the controllable switching means comprises switching transistors.

23. (new) The voltage-controlled oscillator of claim 22, wherein:
the switching transistors are MOSFETs.

24. (new) The voltage-controlled oscillator of claim 19, wherein:
the MOSFETs have gate terminals that are connected to the control input of the control voltage U_{con}.

25. (new) The voltage-controlled oscillator of claim 21, wherein:
the MOSFETs have gate terminals that are connected to the control input of the control voltage U_{con}.

26. (new) The voltage-controlled oscillator of claim 23, wherein:
the MOSFETs have gate terminals that are connected to the control input of the control voltage U_{con}.

27. (new) The voltage-controlled oscillator of claim 24, wherein:

the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

28. (new) The voltage-controlled oscillator of claim 25, wherein:

the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

29. (new) The voltage-controlled oscillator of claim 26, wherein:

the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

30. (new) The voltage-controlled oscillator of claim 27, wherein:

the oscillator is of a CMOS or bipolar technology.

31. (new) The voltage-controlled oscillator of claim 28, wherein:

the oscillator is of a CMOS or bipolar technology.

32. (new) The voltage-controlled oscillator of claim 29, wherein:

the oscillator is of a CMOS or bipolar technology.

33. (new) The voltage-controlled oscillator of claim 10, wherein:

the voltage-controlled capacitance is embodied by means of at least one variable capacitor diode, wherein the effective capacitance depends on the tuning voltage U_{tune} at the tuning input.

34. (new) The voltage-controlled oscillator of claim 33, wherein:

the tuning input of the oscillator is connected to an output of a phase-locked loop and the output of the voltage-controlled oscillator is connected to an input of the phase-locked loop.

REMARKS

The applicant respectfully notes that the translation of the specification as filed does not include an abstract, since the WIPO publication includes an English language abstract. It is that abstract which is relied upon as the abstract in this matter.

In the claims, multiple dependencies have been removed by distributing the limitations. Of the new claims, claim 15 has the limitation of claim 4, but depends from claim 2 rather than claim 1. Claim 16 makes the limitation of claim 4 dependent from claim 3 rather than claim 1. Claim 17 divides out a portion of the limitation of claim 5, and claims 18, 20 and 22 makes the first limitation of claim 5 depend from claims 2-4, respectively. Claims 19, 21 and 23 depend from claims 18, 20 and 22 in the way that claim 17 depends from claim 5.

Claims 24-26 depend from claims 19, 21 and 23 in the way that claim 6 depends from claim 17. Claims 27-29 depend from claims 24-26 in the way that claim 7 depends from claim 6. Claims 30-32 depend from claims 27-29 in the way that claim 8 depends from claim 1.

New claim 33 divides out a portion of the limitaions previously in claim11 and depends from claim11. Claim 34 is a new claim that depnds from claim 33 in the way that claim 12 depends from claim 10.

The above claims have also been amended to correspond them more closely to United States claiming practice, namely, by removing reference numerals, and by clarifying antecedent basis issues. In this manner, they should be in condition for allowance. These amendments to the claims are fully supported by the literal translation into English of the specification as filed in Germany, and they do not introduce new subject matter.

The claims as amended are incorporated into the substitute specification.

Respectfully submitted,

Stephen L. Grant
Reg. No. 33,390
Hahn Loeser & Parks LLP
1225 W. Market St.
Akron, OH 44313
330-864-5550
Fax 330-864-7986
Email: slgrant@hahnlaw.com
Customer No. 021324

7/pts

VOLTAGE-CONTROLLED OSCILLATOR WITH AN LC-RESONANT CIRCUIT

[0001] The invention concerns a voltage-controlled oscillator with an LC-resonant circuit, in particular for implementing integrated voltage-controlled oscillators for the lower GHz range.

BACKGROUND OF THE ART

[0002] Integrated circuits involve using voltage-controlled oscillators which are mostly in the form of ring oscillators or LC-oscillators. Ring oscillators are distinguished by a high degree of frequency tunability. That advantage however is impaired by a strong phase noise and a severe phase jitter. In the case of LC-oscillators frequency tunability is predominantly implemented by means of variable capacitors, for example capacitor diodes. Those oscillators admittedly involve a lower level of phase noise and a lesser degree of phase jitter, but frequency tunability is in most cases seriously reduced.

[0003] Japanese patent application 093 215 38 A describes a voltage-controlled LC-oscillator circuit in which a part of the inductance is short-circuited by means of a switching transistor for given periods of time, whereby the inductive component is reduced at times in such a way that alternate operation of the frequency in two frequency bands is possible.

[0004] Apart from the switching operation which is substantially slower than the period duration in the desired frequency range, such an arrangement does not permit continuous tuning of the frequency in a wide frequency range.

[0005] A similar principle is also described in: A. Krai et al "RF-CMOS-Oscillators with Switched Tuning", Custom Integrated Circuits Conference (CICC'98), pp. 555 – 558. In the case of a fully integrated CMOS-oscillator for a frequency range of between 1 and 2 GHz a tuning range of about 26% is achieved by switching between a plurality of discrete inductance values.

[0006] Besides the use of switching elements which adversely influence phase noise and phase jitter, that arrangement is seen to suffer from the disadvantage that, in spite of the circuit being of a high degree of complexity, it was only possible to achieve a relatively limited frequency tuning range. In addition the switching of

discrete inductance values means that it is only possible to achieve quasi-continuous frequency tuning which has to be supplemented by capacitive tuning.

[0007] In integrated radio systems the oscillator must enjoy a relatively great tuning range in order to compensate for technology and temperature fluctuations and to cover the receiving and transmitting band respectively.

[0008] With operating voltages in modern technologies becoming smaller and smaller the available voltage range for the control voltage of the voltage-controlled oscillator (VCO) is becoming progressively smaller. That means that the necessary sensitivity of the oscillation frequency of the oscillator in relation to control voltage variations increases. The consequence of this is that, upon integration of the VCO into a phase-locked loop (PLL) the noise of the control voltage causes severe phase noise. That problem is becoming more acute with down-scaling of the technology, which goes hand-in-hand with the reduction in the supply voltage.

[0009] Therefore the object of the invention is to propose a voltage-controlled oscillator with an LC-resonant circuit, with which the disadvantages of the state of the art are overcome and with which continuous frequency tunability in a wide range can be achieved in particular with a low level of phase noise and a low level of phase jitter.

SUMMARY OF THE INVENTION

[0010] In accordance with the invention that object is attained in that, in a voltage-controlled oscillator with an LC-resonant circuit there can be periodically switched in parallel and/or in series with at least one inductor a further inductor by way of a switching means actuated with the oscillator frequency and that a control input of the switching means is connected to a variable dc voltage. Advantageously a further inductor can be periodically switched in parallel and/or series with a plurality of inductors by way of a respective controllable switching means. The controllable switching means are periodically in a conducting state and then a non-conducting state. They are controllable by a variable control voltage. In that respect the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means is variable within an oscillation period of the oscillator in dependence on the value of the control voltage. In accordance with the relationship of the duration of the conducting state and the

duration of the non-conducting state of the switching means within an oscillation period of the oscillator the time-averaged effective inductance is variable in dependence on the value of the control voltage. The controllable switching means are advantageously switching transistors and in particular MOSFETs whose gate terminals are connected to the input of the control voltage and whose source terminals are connected to parts of the circuit arrangement carrying the oscillator frequency. Advantageously the oscillator is constructed using a CMOS or bipolar technology and can preferably be used in frequency synthesizers for wide-band systems and for multi-band uses and for clock generation and clock recovery in high-speed circuits such as for example microprocessors and memories.

[0011] The teaching of the invention involves replacing the coils in a resonant circuit by pairs of coils which are connected in parallel and/or in series and of which a respective one of the coils is connected to a switch which is periodically opened and closed. That means that in each case only one coil or the parallel and/or series connection of both coils is operative. The period of time during which the switch is closed within an oscillation period is controlled by a control voltage. The time-averaged effective inductance can thus be altered in a wide range. This results in the desired continuous frequency tunability.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The features of the invention, besides being set forth in the claims, are also to be found in the description and the drawings, in which respect the individual features each on their own or in pluralities in the form of sub-combinations represent patentable configurations in respect of which protection is claimed herein. Embodiments by way of example of the invention are described in greater detail hereinafter. In the accompanying drawings:

[0013] Figure 1 shows a voltage-controlled oscillator according to the invention,

[0014] Figure 2 shows a diagram of the oscillator frequency as a function of the control voltage,

[0015] Figure 3 shows a further embodiment of the oscillator according to the invention,

[0016] Figure 4 shows a voltage-controlled oscillator according to the invention,

[0017] Figure 5 shows a further embodiment by way of example of the oscillator according to the invention,

[0018] Figure 6 shows a combination circuit of a VCO with a PLL, and

[0019] Figure 7 shows a combination circuit of a VCO with two PLLs.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Example 1:

[0020] Figure 1 shows an LC-oscillator according to the invention with two co-operating semiconductor switches and a capacitor C. The inductors L_1 are arranged in two branches. Associated with each of the two inductors L_1 is a respective further inductor L_2 which can be switched in parallel with the first inductors L_1 by way of a respective switching means S_v. The gate terminals G of the switching means S_v which are in the form of MOSFETs are connected to an input V_{con} for a control voltage U_{con} while the source terminals S are connected to the output of the oscillator, which carries the oscillator frequency.

[0021] Figure 2 shows a diagram in respect of the oscillator frequency in GHz as a function of the control voltage U_{con}.

[0023] The mode of operation of the oscillator according to the invention is as follows: the two switching means S_v, in this embodiment being two MOSFETs, are opened at a low control voltage U_{con} during the major part of an oscillation period of the oscillator. That state occurs as long as the gate-source voltage does not exceed the switching point of the switching means S_v. During the duration of the non-conducting state of the switching means S_v only the first inductors L_1 are effective. For a small part of the oscillation period the gate-source voltage exceeds the switching point of the switching means S_v. For the duration of the now conducting state of the switching means S_v the further inductors L_2 are connected in parallel with the first inductors L_1 whereby the total value of the effective inductance reduces as a function of time. In accordance with the relationship of the longer duration of the non-conducting state of the switching means S_v to the shorter duration of the conducting state thereof, there is a relatively great, time-

averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly low.

[0024] With an increased control voltage U_{con} the two switching means S_v are opened only during a smaller part of the oscillation period and are closed during the major part thereof. In accordance with the relationship of the shorter duration of the non-conducting state of the switching means S_v to the longer duration of the conducting state thereof there is therefore a relatively low, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly high.

[0025] As a special case it will be assumed that the inductance and quality of the pairs of coils L_1 and L_2 are identical and involve the same magnitudes L1 and Q1. For the situation involving ideal switching means S_v, the following then apply in regard to the inductance L and the quality Q of the overall arrangement comprising L_1, L_2 and the switch:

L = L1, Q = Q1 when the switching means S_v are opened, and

L = L1/2, Q = Q1 when the switching means S_v are closed.

[0026] Closure of the switching means S_v therefore causes halving of the inductance which is crucial in terms of the oscillator frequency. The quality of the pairs of coils L_1 and L_2 is equal to the quality of the individual coil. If it is considered that the following approximately applies for the oscillator frequency:

$$f_0 = 1./\sqrt{L},$$

the following relationship is found for the lower limit frequency f_0,min and for the upper limit frequency f_0,max for the frequency tuning range:

$$f_0, \max = \sqrt{2 \cdot fo, \min}$$

[0027] The following similarly applies for the general case of coils which are not necessarily the same:

$$f_0, \max = \sqrt{(1 + L1/L2) \cdot fo, \min}$$

[0028] Thus the frequency tuning range can still be further increased by the choice of a greater ratio of L1/L2.

[0029] Figure 2 shows the simulated frequency tuning range in the form of a diagram showing the oscillator frequency f_0 as a function of the control voltage U_{con} for L1/L2 = 2. In this embodiment the frequency tuning range is about 1.25 GHz, that is to say more than an octave.

[0030] The oscillator according to the invention can be implemented in a fully integrated configuration both using CMOS technology and also bipolar technology. It can advantageously be used in frequency synthesizers for wide-band systems and for multi-band uses and for clock production and clock recovery in high-speed circuits such as microprocessors and memories.

Example 2:

[0031] As a further embodiment by way of example Figure 3 shows a circuit arrangement of the oscillator according to the invention with two respective first inductors L_1, L_3, in relation to each of which a further respective inductor L_2 can be connected in parallel.

[0032] The frequency tuning range can be increased by the use of more than two inductors L_1, L_2, as demonstrated in Figure 3.

Example 3:

[0033] Figure 4 shows an LC-oscillator according to the invention with two co-operating semiconductor switches and a capacitor C. The inductors L_1 are arranged in two branches. Associated with each of the two inductors L_1 is a respective further inductor L_2 which can be connected in series with the first inductors L_1 by a respective switching means S_v. The gate terminals G of the switching means S_v which are in the form of MOSFETs are connected to an input V_{con} for a control voltage U_{con} while the source terminals S are connected to the output of the oscillator, which carries the oscillator frequency.

[0034] When the switching means S_v is closed the total inductance is of a lower value than when the switching means S_v is opened. The switching means S_v is modulated at the oscillation frequency.

[0035] The mode of operation of the oscillator according to the invention is as follows: the two switching means S_v, in this embodiment being two MOSFETs, are opened with a low voltage U_{con} at the input V_{con} during the major part of an oscillation period of the oscillator. That state occurs as long as the gate-source voltage does not exceed the switching point of the switching means S_v. During the duration of the non-conducting state of the switching means S_v the further inductors L_2 are effective, in relation to the first inductors L_1, whereby the total value of the effective inductance is increased. For a small part of the oscillation period the gate-source voltage exceeds the switching point of the switching means

S_v. Only the first inductors L_1 are effective for the duration of the now conducting state of the switching means S_v. In accordance with the relationship of the longer duration of the non-conducting state of the switching means S_v to the shorter duration of the conducting state thereof, there is a relatively high, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly low.

[0036] With an increased control voltage U_{con} the two switching means S_v are only opened during a smaller part of the oscillation period and closed during the greater part thereof. In accordance with the relationship of the shorter duration of the non-conducting state of the switching means S_v to the longer duration of the conducting state thereof, there is a relatively low, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly higher than with a lower control voltage U_{con}.

Example 4:

[0037] Figure 5 shows a combination of inductive and capacitive tuning. Besides inductive tuning, capacitive tuning is also possible.

[0038] Inductive tuning is based on the principle described in the preceding embodiments. In this embodiment the inductors L_1 and L_2 are connected in parallel. The two switching means S_v are opened at a low control voltage U_{con} at the input V_{con} during the major part of an oscillation period of the oscillator. That state occurs as long as the gate-source voltage does not exceed the switching point of the switching means S_v. During the duration of the non-conducting state of the switching means S_v only the first inductors L1 are effective. For a small part of the oscillation period the gate-source voltage exceeds the switching point of the switching means S_v. For the duration of the now conducting state of the switching means S_v the further inductors L2 are connected in parallel with the first inductors L1 whereby the total value of the effective inductance decreases as a function of time. In accordance with the relationship of the longer duration of the non-conducting state of the switching means S_v to the shorter duration of the conducting state thereof there is a relatively high time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly low.

[0039] With an increased control voltage U_{con} the two switching means S_v are opened only during a smaller part of the oscillation period and are closed during the

major part thereof. In accordance with the relationship of the shorter duration of the non-conducting state of the switching means S_v to the longer duration of the conducting state thereof there is a relatively low, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly high.

[0040] To provide for capacitive tuning integrated in the resonant circuit is a variable capacitance which in this embodiment is embodied by means of two p-MOSFETs M_1, M_2 in the form of variable capacitor diodes. The control input V_{con} permits tuning of the frequency on the basis of the principle described in the preceding embodiments while a tuning voltage U_{tune} at the tuning input V_{tune} determines the oscillation frequency by way of the time-averaged capacitance. It is now possible to use the control input V_{con} in order to compensate for technology fluctuations while the tuning input V_{tune} is used for fine tuning by means of a phase-locked loop PLL, as shown in Figure 6. In this case, the tuning input V_{tune} of the VCO is connected to the output of the phase-locked loop PLL and the oscillator output of the voltage-controlled oscillator VCO is connected to the input of the phase-locked loop PLL.

[0041] In this case it is possible to use a relatively low VCO-gain $K = df_0/dU_{tune}$. In that way the effect of noise within the phase-locked loop PLL on the phase noise of the voltage-controlled oscillator VCO is minimized. The noise of the inductive control voltage at the control input V_{con} can be blocked by means of a large capacitance.

Example 5:

[0042] A modified variant is illustrated in Figure 7. There, the oscillator output is connected to the inputs of two phase-locked loops PLL1 and PLL2. The tuning input V_{tune} of the voltage-controlled oscillator VCO is connected to the output of the phase-locked loop PLL1 while the control input V_{con} of the voltage-controlled oscillator VCO is connected to the output of the phase-locked loop PLL2.

[0043] The phase-locked loop PLL2 serves to compensate for technology and temperature fluctuations while the phase-locked loop PLL1 serves for fine tuning of the oscillation frequency.

[0044] This method is particularly suitable for a modulation method which is referred to as frequency hopping. This is a special code division multiple access method (CDMA) in which the transmitting and receiving frequency are altered in

respect of time in accordance with a predetermined code. This can be implemented by means of the phase-locked loop PLL1 while the very slow phase-locked loop PLL2 provides for coarse setting of the frequency.

[0045] A use of the invention is the "Bluetooth" standard for wireless communication over short distances. The frequency hopping method is used there. The demands in terms of phase noise are not too high there, which makes an integrated CMOS-solution a possibility.

[0046] A voltage-controlled oscillator with an LC-resonant circuit was described in the foregoing description by means of specific embodiments. It should be noted however that the present invention is not limited to the details of the description in the specific embodiments as modifications and alterations are claimed within the scope of the claims.

CLAIMS

What is claimed is:

1. (amended) A voltage-controlled oscillator oscillating at an oscillator frequency comprising:

an LC-resonant circuit with at least one inductor;

a controllable switching means which is arranged in the LC-resonant circuit in such a way that it periodically has a conducting and a non-conducting state at the oscillator frequency and has a control input connected to a variable dc voltage, the control voltage U_{con}; and

a further inductor which can be periodically switched in parallel or in series with the inductor by way of the switching means actuated at the oscillator frequency.

2. (amended) The voltage-controlled oscillator of claim 1, further comprising:

a further inductor, periodically connected in parallel or in series with a plurality of inductors by way of a respective controllable switching means at the oscillator frequency and the controllable switching means is controllable by a variable control voltage U_{con}.

3. (amended) The voltage-controlled oscillator of claim1, wherein:

the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means within an oscillation period of the oscillator varies, depending on the control voltage U_{con}.

4. (amended) The voltage-controlled oscillator of claim 1, wherein:

the time-averaged effective inductance varies, depending on the control voltage U_{con} according to the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means within an oscillation period of the oscillator.

5. (amended) The voltage-controlled oscillator of claim1, wherein:

the controllable switching means comprises switching transistors.

6. (amended) The voltage-controlled oscillator of claim 17, wherein:

the MOSFETs have gate terminals that are connected to the control input of the control voltage U_{con}.

7. (amended) The voltage-controlled oscillator of claim 6, wherein:

the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

8. (amended) The voltage-controlled oscillator of claim 1, wherein:

the oscillator is of a CMOS or bipolar technology.

9. (amended) The voltage-controlled oscillator of claim 1, wherein:

the oscillator is used in frequency synthesizers for wide-band systems and for multi-band uses and for clock production and clock recovery in high-speed circuits such as for example microprocessors and memories.

10. (amended) The voltage-controlled oscillator of claim 1, wherein:

a voltage-controlled capacitance is integrated in the oscillator, which is connected to a tuning voltage U_{tune} by way of a further control input, the tuning input.

11. (amended) The voltage-controlled oscillator of claim 10, wherein:

the voltage-controlled capacitance is embodied by means of at least one variable capacitor diode, wherein the effective capacitance depends on the tuning voltage U_{tune} at the tuning input.

12. (amended) The voltage-controlled oscillator of claim 10, wherein:

the tuning input of the oscillator is connected to an output of a phase-locked loop and the output of the voltage-controlled oscillator is connected to an input of the phase-locked loop.

13. (amended) The voltage-controlled oscillator of claim 1, wherein:

the noise of the control voltage at the control input is blocked out by means of a high capacitance between the control input and ground.

14. (amended) The voltage-controlled oscillator of claim 10, wherein:

the tuning input of the voltage-controlled oscillator is connected to the output of a phase-locked loop and the control input of the voltage-controlled oscillator is connected to an output of a further phase-locked loop.

15. (new) The voltage-controlled oscillator of claim 2, wherein:

the time-averaged effective inductance varies, depending on the control voltage U_{con} according to the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means within an oscillation period of the oscillator.

16. (new) The voltage-controlled oscillator of claim 3, wherein:

the time-averaged effective inductance varies, depending on the control voltage U_{con} according to the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means within an oscillation period of the oscillator.

17. (new) The voltage-controlled oscillator of claim 5, wherein:
the switching transistors are MOSFETs.

18. (new) The voltage-controlled oscillator of claim 2, wherein:
the controllable switching means comprises switching transistors.

19. (new) The voltage-controlled oscillator of claim 18, wherein:
the switching transistors are MOSFETs.

20. (new) The voltage-controlled oscillator of claim 3, wherein:
the controllable switching means comprises switching transistors.

21. (new) The voltage-controlled oscillator of claim 20, wherein:
the switching transistors are MOSFETs.

22. (new) The voltage-controlled oscillator of claim 4, wherein:
the controllable switching means comprises switching transistors.

23. (new) The voltage-controlled oscillator of claim 22, wherein:
the switching transistors are MOSFETs.

24. (new) The voltage-controlled oscillator of claim 19, wherein:
the MOSFETs have gate terminals that are connected to the control input of the control voltage U_{con}.

25. (new) The voltage-controlled oscillator of claim 21, wherein:
the MOSFETs have gate terminals that are connected to the control input of the control voltage U_{con}.

26. (new) The voltage-controlled oscillator of claim 23, wherein:
the MOSFETs have gate terminals that are connected to the control input of the control voltage U_{con}.

27. (new) The voltage-controlled oscillator of claim 24, wherein:
the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

28. (new) The voltage-controlled oscillator of claim 25, wherein:
the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

29. (new) The voltage-controlled oscillator of claim 26, wherein:
the MOSFETs have source terminals that are connected to parts of the circuit arrangement carrying the oscillator frequency.

30. (new) The voltage-controlled oscillator of claim 27, wherein:
the oscillator is of a CMOS or bipolar technology.

31. (new) The voltage-controlled oscillator of claim 28, wherein:
the oscillator is of a CMOS or bipolar technology.

32. (new) The voltage-controlled oscillator of claim 29, wherein:
the oscillator is of a CMOS or bipolar technology.

33. (new) The voltage-controlled oscillator of claim 10, wherein:
the voltage-controlled capacitance is embodied by means of at least one variable capacitor diode, wherein the effective capacitance depends on the tuning voltage U_{tune} at the tuning input.

34. (new) The voltage-controlled oscillator of claim 33, wherein:
the tuning input of the oscillator is connected to an output of a phase-locked loop and the output of the voltage-controlled oscillator is connected to an input of the phase-locked loop.

Voltage-controlled oscillator with an LC-resonant circuit

The invention concerns a voltage-controlled oscillator with an LC-resonant circuit, in particular for implementing integrated voltage-controlled oscillators for the lower GHz range.

Integrated circuits involve using voltage-controlled oscillators which are mostly in the form of ring oscillators or LC-oscillators. Ring oscillators are distinguished by a high degree of frequency tunability. That advantage however is impaired by a strong phase noise and a severe phase jitter. In the case of LC-oscillators frequency tunability is predominantly implemented by means of variable capacitors, for example capacitor diodes. Those oscillators admittedly involve a lower level of phase noise and a lesser degree of phase jitter, but frequency tunability is in most cases seriously reduced.

JP 093 215 38 A describes a voltage-controlled LC-oscillator circuit in which a part of the inductance is short-circuited by means of a switching transistor for given periods of time, whereby the inductive component is reduced at times in such a way that alternate operation of the frequency in two frequency bands is possible.

Apart from the switching operation which is substantially slower than the period duration in the desired frequency range, such an arrangement does not permit continuous tuning of the frequency in a wide frequency range.

A similar principle is also described in: A. Kral et al "RF-CMOS-Oscillators with Switched Tuning", Custom Integrated Circuits Conference (CICC'98), pp. 555 - 558. In the case of a fully integrated CMOS-oscillator for a frequency range of between 1 and 2 GHz a tuning range of about 26% is achieved by switching between a plurality of discrete inductance values.

Besides the use of switching elements which adversely influence phase noise and phase jitter, that arrangement is seen to suffer from the disadvantage that, in spite of the circuit being of a high degree of complexity, it was only possible to achieve a relatively limited frequency tuning range. In addition the switching of discrete inductance values means that it is only possible to achieve quasi-continuous frequency tuning which has to be supplemented by capacitive tuning.

In integrated radio systems the oscillator must enjoy a relatively great tuning range in order to compensate for technology and temperature fluctuations and to cover the receiving and transmitting band respectively.

With operating voltages in modern technologies becoming smaller and smaller the available voltage range for the control voltage of the voltage-controlled oscillator (VCO) is becoming progressively smaller. That means that the necessary sensitivity of the oscillation frequency of the oscillator in relation to control voltage variations increases. The consequence of this is that, upon integration of the VCO into a phase-locked loop (PLL) the noise of the control voltage causes severe phase noise. That problem is becoming more acute with down-scaling of the technology, which goes hand-in-hand with the reduction in the supply voltage.

Therefore the object of the invention is to propose a voltage-controlled oscillator with an LC-resonant circuit, with which the disadvantages of the state of the art are overcome and with which continuous frequency tunability in a wide range can be achieved in particular with a low level of phase noise and a low level of phase jitter.

In accordance with the invention that object is attained in that, in a voltage-controlled oscillator with an LC-resonant circuit there can be periodically switched in parallel and/or in series with at least one inductor a further inductor by way of a switching means actuated with the oscillator frequency and that a control input of the switching means is connected to

a variable dc voltage. Advantageously a further inductor can be periodically switched in parallel and/or series with a plurality of inductors by way of a respective controllable switching means. The controllable switching means are periodically in a conducting state and then a non-conducting state. They are controllable by a variable control voltage. In that respect the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means is variable within an oscillation period of the oscillator in dependence on the value of the control voltage. In accordance with the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means within an oscillation period of the oscillator the time-averaged effective inductance is variable in dependence on the value of the control voltage. The controllable switching means are advantageously switching transistors and in particular MOSFETs whose gate terminals are connected to the input of the control voltage and whose source terminals are connected to parts of the circuit arrangement carrying the oscillator frequency. Advantageously the oscillator is constructed using a CMOS or bipolar technology and can preferably be used in frequency synthesizers for wide-band systems and for multi-band uses and for clock generation and clock recovery in high-speed circuits such as for example microprocessors and memories.

The teaching of the invention involves replacing the coils in a resonant circuit by pairs of coils which are connected in parallel and/or in series and of which a respective one of the coils is connected to a switch which is periodically opened and closed. That means that in each case only one coil or the parallel and/or series connection of both coils is operative. The period of time during which the switch is closed within an oscillation period is controlled by a control voltage. The time-averaged effective inductance can thus be altered in a wide range. This results in the desired continuous frequency tunability.

The features of the invention, besides being set forth in the claims, are also to be found in the description and the drawings, in which respect the individual features each on their own or in pluralities in the form of sub-combinations represent patentable configurations in respect of which protection is claimed herein. Embodiments by way of example of the invention are described in greater detail hereinafter. In the accompanying drawings:

Figure 1 shows a voltage-controlled oscillator according to the invention,

Figure 2 shows a diagram of the oscillator frequency as a function of the control voltage,

Figure 3 shows a further embodiment of the oscillator according to the invention,

Figure 4 shows a voltage-controlled oscillator according to the invention,

Figure 5 shows a further embodiment by way of example of the oscillator according to the invention,

Figure 6 shows a combination circuit of a VCO with a PLL, and

Figure 7 shows a combination circuit of a VCO with two PLLs.

Example 1:

Figure 1 shows an LC-oscillator according to the invention with two co-operating semiconductor switches and a capacitor C. The inductors L_1 are arranged in two branches. Associated with each of the two inductors L_1 is a respective further inductor L_2 which can be switched in parallel with the first inductors L_1 by way of a respective switching means S_v. The gate terminals G of the switching means S_v which are in the form of MOSFETs are connected to an input V_{con} for a control voltage U_{con} while the source terminals S are connected to the output of the oscillator, which carries the oscillator frequency.

Figure 2 shows a diagram in respect of the oscillator frequency in GHz as a function of the control voltage U_{con}.

The mode of operation of the oscillator according to the invention is as follows: the two switching means S_v, in this embodiment being two MOSFETs, are opened at a low control voltage U_{con} during the major part of an oscillation period of the oscillator. That state occurs as long as the gate-source voltage does not exceed the switching point of the switching means S_v. During the duration of the non-conducting state of the switching means S_v only the first inductors L_1 are effective. For a small part of the oscillation period the gate-source voltage exceeds the switching point of the switching means S_v. For the duration of the now conducting state of the switching means S_v the further inductors L_2 are connected in parallel with the first inductors L_1 whereby the total value of the effective inductance reduces as a function of time. In accordance with the relationship of the longer duration of the non-conducting state of the switching means S_v to the shorter duration of the conducting state thereof, there is a relatively great, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly low.

With an increased control voltage U_{con} the two switching means S_v are opened only during a smaller part of the oscillation period and are closed during the major part thereof. In accordance with the relationship of the shorter duration of the non-conducting state of the switching means S_v to the longer duration of the conducting state thereof there is therefore a relatively low, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly high.

As a special case it will be assumed that the inductance and quality of the pairs of coils L_1 and L_2 are identical and involve the same magnitudes L1 and Q1. For the situation involving ideal switching means S_v, the following then apply in regard to the inductance L and the quality Q of the overall arrangement comprising L_1, L_2 and the switch:

$L = L1$, $Q = Q1$ when the switching means S_v are opened, and

$L = L1/2$, $Q = Q1$ when the switching means S_v are closed.

Closure of the switching means S_v therefore causes halving of the inductance which is crucial in terms of the oscillator frequency. The quality of the pairs of coils L_1 and L_2 is equal to the quality of the individual coil. If it is considered that the following approximately applies for the oscillator frequency:

$$f_0 = 1./\sqrt{L},$$

the following relationship is found for the lower limit frequency f_0,min and for the upper limit frequency f_0,max for the frequency tuning range:

$$f_0,\max = \sqrt{2 \cdot fo,\min}$$

The following similarly applies for the general case of coils which are not necessarily the same:

$$f_0,\max = \sqrt{(1 + L1/L2) \cdot fo,\min}$$

Thus the frequency tuning range can still be further increased by the choice of a greater ratio of L1/L2.

Figure 2 shows the simulated frequency tuning range in the form of a diagram showing the oscillator frequency f_0 as a function of the control voltage U_{con} for L1/L2 = 2. In this embodiment the frequency tuning range is about 1.25 GHz, that is to say more than an octave.

The oscillator according to the invention can be implemented in a fully integrated configuration both using CMOS technology and also bipolar technology. It can advantageously be used in frequency synthesizers for wide-band systems and for multi-band uses and for clock production and clock recovery in high-speed circuits such as microprocessors and memories.

Example 2:

As a further embodiment by way of example Figure 3 shows a circuit arrangement of the oscillator according to the invention with two respective first inductors L_1, L_3, in relation to each of which a further respective inductor L_2 can be connected in parallel.

Example 3:

Figure 4 shows an LC-oscillator according to the invention with two co-operating semiconductor switches and a capacitor C. The inductors L_1 are arranged in two branches. Associated with each of the two inductors L_1 is a respective further inductor L_2 which can be connected in series with the first inductors L_1 by a respective switching means S_v. The gate terminals G of the switching means S_v which are in the form of MOSFETs are connected to an input V_{con} for a control voltage U_{con} while the source terminals S are connected to the output of the oscillator, which carries the oscillator frequency.

When the switching means S_v is closed the total inductance is of a lower value than when the switching means S_v is opened. The switching means S_v is modulated at the oscillation frequency.

The mode of operation of the oscillator according to the invention is as follows: the two switching means S_v, in this embodiment being two MOSFETs, are opened with a low voltage U_{con} at the input V_{con} during the major part of an oscillation period of the oscillator. That state occurs as long as the gate-source voltage does not exceed the switching point of the switching means S_v. During the duration of the non-conducting state of the switching means S_v the further inductors L_2 are effective, in relation to the first inductors L_1, whereby the total value of the effective inductance is increased. For a small part of the oscillation period the gate-source voltage exceeds the switching point of the switching means S_v. Only the first inductors L_1 are effective for the duration of the now conducting state of the switching means S_v. In accordance with the relationship of the longer duration of the non-conducting state of the switching means S_v to the shorter duration of the conducting state thereof, there is a relatively high, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly low.

With an increased control voltage U_{con} the two switching means S_v are only opened during a smaller part of the oscillation period and closed

during the greater part thereof. In accordance with the relationship of the shorter duration of the non-conducting state of the switching means S_v to the longer duration of the conducting state thereof, there is a relatively low, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly higher than with a lower control voltage U_{con}.

Example 4:

Figure 5 shows a combination of inductive and capacitive tuning. Besides inductive tuning, capacitive tuning is also possible.

Inductive tuning is based on the principle described in the preceding embodiments. In this embodiment the inductors L_1 and L_2 are connected in parallel. The two switching means S_v are opened at a low control voltage U_{con} at the input V_{con} during the major part of an oscillation period of the oscillator. That state occurs as long as the gate-source voltage does not exceed the switching point of the switching means S_v. During the duration of the non-conducting state of the switching means S_v only the first inductors L1 are effective. For a small part of the oscillation period the gate-source voltage exceeds the switching point of the switching means S_v. For the duration of the now conducting state of the switching means S_v the further inductors L2 are connected in parallel with the first inductors L1 whereby the total value of the effective inductance decreases as a function of time. In accordance with the relationship of the longer duration of the non-conducting state of the switching means S_v to the shorter duration of the conducting state thereof there is a relatively high time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly low.

With an increased control voltage U_{con} the two switching means S_v are opened only during a smaller part of the oscillation period and are closed during the major part thereof. In accordance with the relationship of the shorter duration of the non-conducting state of the switching means S_v to the longer duration of the conducting state thereof there is a

relatively low, time-averaged effective inductance. The oscillator frequency resulting therefrom is correspondingly high.

To provide for capacitive tuning integrated in the resonant circuit is a variable capacitance which in this embodiment is embodied by means of two p-MOSFETs M_1, M_2 in the form of variable capacitor diodes. The control input V_{con} permits tuning of the frequency on the basis of the principle described in the preceding embodiments while a tuning voltage U_{tune} at the tuning input V_{tune} determines the oscillation frequency by way of the time-averaged capacitance. It is now possible to use the control input V_{con} in order to compensate for technology fluctuations while the tuning input V_{tune} is used for fine tuning by means of a phase-locked loop PLL, as shown in Figure 6. In this case, the tuning input V_{tune} of the VCO is connected to the output of the phase-locked loop PLL and the oscillator output of the voltage-controlled oscillator VCO is connected to the input of the phase-locked loop PLL.

In this case it is possible to use a relatively low VCO-gain $K = df_0/dU_{tune}$. In that way the effect of noise within the phase-locked loop PLL on the phase noise of the voltage-controlled oscillator VCO is minimized. The noise of the inductive control voltage at the control input V_{con} can be blocked by means of a large capacitance.

Example 5:

A modified variant is illustrated in Figure 7. There, the oscillator output is connected to the inputs of two phase-locked loops PLL1 and PLL2. The tuning input V_{tune} of the voltage-controlled oscillator VCO is connected to the output of the phase-locked loop PLL1 while the control input V_{con} of the voltage-controlled oscillator VCO is connected to the output of the phase-locked loop PLL2.

The phase-locked loop PLL2 serves to compensate for technology and temperature fluctuations while the phase-locked loop PLL1 serves for fine tuning of the oscillation frequency.

This method is particularly suitable for a modulation method which is referred to as frequency hopping. This is a special code division multiple access method (CDMA) in which the transmitting and receiving frequency are altered in respect of time in accordance with a predetermined code. This can be implemented by means of the phase-locked loop PLL1 while the very slow phase-locked loop PLL2 provides for coarse setting of the frequency.

A use of the invention is the "Bluetooth" standard for wireless communication over short distances. The frequency hopping method is used there. The demands in terms of phase noise are not too high there, which makes an integrated CMOS-solution a possibility.

A voltage-controlled oscillator with an LC-resonant circuit was described in the foregoing description by means of specific embodiments. It should be noted however that the present invention is not limited to the details of the description in the specific embodiments as modifications and alterations are claimed within the scope of the claims.

CLAIMS

1. A voltage-controlled oscillator (VCO) oscillating at an oscillator frequency comprising

- an LC-resonant circuit with at least one inductor (L_1)

- a controllable switching means (S_v) which is arranged in the LC-resonant circuit in such a way that it periodically has a conducting and a non-conducting state at the oscillator frequency and has a control input (V_{con}) connected to a variable dc voltage, the control voltage U_{con}, and

- a further inductor (L_2) which can be periodically switched in parallel or in series with the inductor (L_1) by way of the switching means (S_v) actuated at the oscillator frequency.

2. A voltage-controlled oscillator (VCO) as set forth in claim 1 characterized in that a further inductor (L_2) can be periodically connected in parallel or in series with a plurality of inductors (L_1) by way of a respective controllable switching means (S_v) at the oscillator frequency and the controllable switching means (S_v) are controllable by a variable control voltage U_{con}.

3. A voltage-controlled oscillator (VCO) as set forth in claim 1 characterized in that the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means (S_v) within an oscillation period of the oscillator (VCO) is variable in dependence on the control voltage U_{con}.

4. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that the time-averaged effective inductance is variable in dependence on the control voltage U_{con} in accordance with the relationship of the duration of the conducting state and the duration of the non-conducting state of the switching means (S_v) within an oscillation period of the oscillator (VCO).

5. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that the controllable switching means (S_v) are switching transistors, in particular MOSFETs.

6. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that gate terminals (G) of the MOSFETs are connected to the control input (V_{con}) of the control voltage U_{con}.

7. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that source terminals (S) of the MOSFETs are connected to parts of the circuit arrangement carrying the oscillator frequency.

8. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that the oscillator (VCO) is of a CMOS or bipolar technology.

9. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that the oscillator (VCO) is used in frequency synthesizers for wide-band systems and for multi-band uses and for clock production and clock recovery in high-speed circuits such as for example microprocessors and memories.

10. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that in addition to the voltage-controlled inductance a voltage-controlled capacitance is integrated in the oscillator (VCO), which is connected to a tuning voltage U_{tune} by way of a further control input, the tuning input (V_{tune}).

11. A voltage-controlled oscillator (VCO) as set forth in claim 10 characterized in that the voltage-controlled capacitance is embodied by means of at least one variable capacitor diode, in particular by means of two p-MOSFETs (M_1, M_2), wherein the effective capacitance depends on the tuning voltage U_{tune} at the tuning input (V_{tune}).

12. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that the tuning input (V_{tune}) of the oscillator (VCO) is connected to an output of a phase-locked loop (PLL) and the output of the voltage-controlled oscillator (VCO) is connected to an input of the phase-locked loop (PLL).

13. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that the noise of the control voltage at the control input (V_{con}) is blocked out by means of a high capacitance between the control input (V_{con}) and ground.

14. A voltage-controlled oscillator (VCO) as set forth in one or more of the preceding claims characterized in that the tuning input (V_{tune}) of the voltage-controlled oscillator (VCO) is connected to the output of the phase-locked loop (PLL; PLL1) and the control input (V_{con}) of the voltage-controlled oscillator (VCO) is connected to an output of a further phase-locked loop (PLL2).

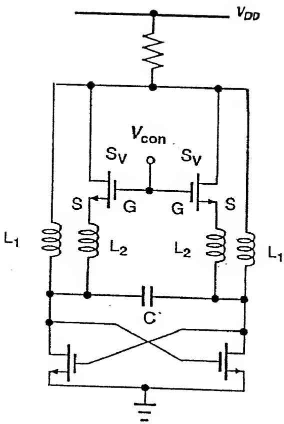

Fig. 1

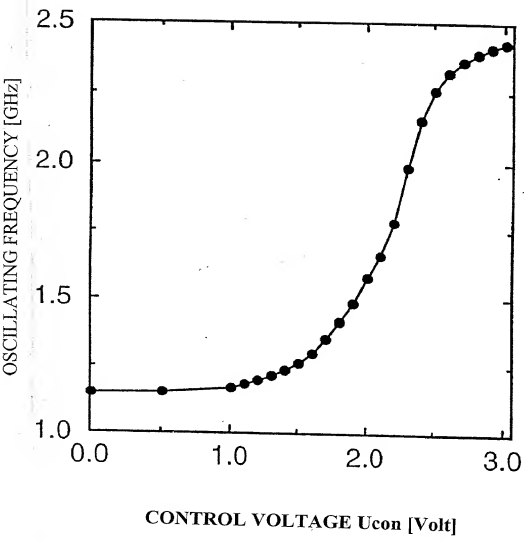

Fig. 2

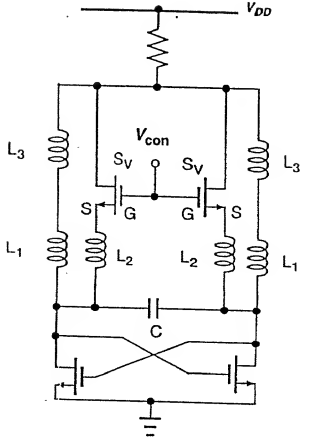

Fig. 3

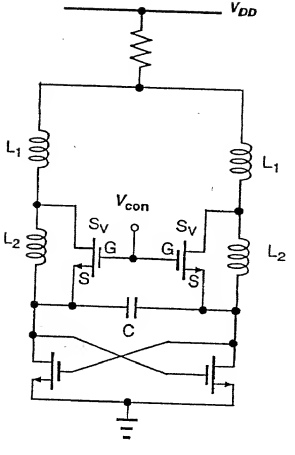

Fig. 4

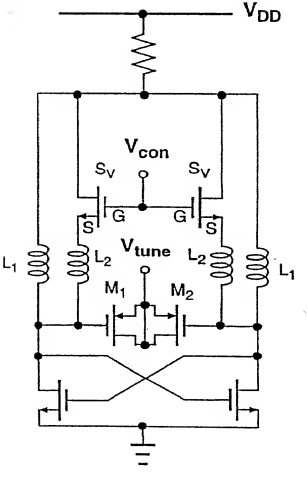

Fig. 5

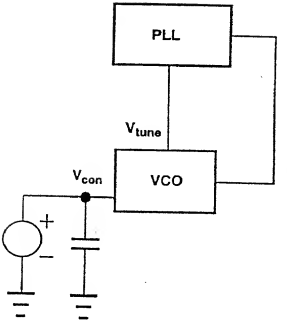

Fig. 6

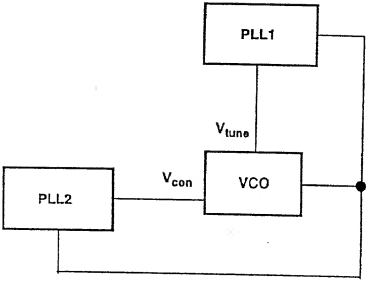

Fig. 7

COMBINED DECLARATION AND POWER OF ATTORNEY

(ORIGINAL, DESIGN, NATIONAL STAGE OF PCT, SUPPLEMENTAL, DIVISIONAL, CONTINUATION, OR C-I-P)

As a below named inventor, I hereby declare that:

TYPE OF DECLARATION

This declaration is for a national stage of PCT application.

INVENTORSHIP IDENTIFICATION

My residence, post office address and citizenship are as stated below, next to my name. I believe that I am an original, first and joint inventor of the subject matter that is claimed, and for which a patent is sought on the invention entitled:

TITLE OF INVENTION

VOLTAGE-CONTROLLED OSCILLATOR WITH LC RESONANT CIRCUIT

SPECIFICATION IDENTIFICATION

The specification was described and claimed in PCT International Application No. DE00/01385 filed on April 26, 2000 and amended on 20 March 2001.

ACKNOWLEDGMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information, which is material to patentability as defined in 37, Code of Federal Regulations, Section 1.56, and which is material to the examination of this application, namely, information where there is a substantial likelihood that a reasonable Examiner would consider it important in deciding whether to allow the application to issue as a patent .

PRIORITY CLAIM (35 U.S.C. Section 119(a)-(d))

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

Such applications have been filed as follows.

PRIOR FOREIGN APPLICATION(S) FILED WITHIN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS APPLICATION AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. SECTION 119(a)-(d)

COUNTRY	APPLICATION NUMBER	DATE OF FILING DAY, MONTH, YEAR	PRIORITY CLAIMED UNDER 35 U.S.C. SECTION 119
Germany	199 25 742.6	5 June 1999	yes
Germany	100 21 273.5	26 April 2000	yes

POWER OF ATTORNEY

I hereby appoint the following practitioner(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

APPOINTED PRACTITIONER(S)	REGISTRATION NUMBER(S)
Stephen L. Grant	33390
Eryn R. Ace	44491
Alexander D. Bommarito	44036
Robert J. Clark	45835
John D. DeLong	44648
R. Eric Gaum	39199
Michael H. Minns	31985
Edwin W. Oldham	22003
Scott M. Oldham	32712
Mark A. Watkins	33813

I hereby appoint the practitioner(s) associated with the Customer Number provided below to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

SEND CORRESPONDENCE TO

Stephen L. Grant
1225 W. Market St.
Akron, OH 44313
USA

Customer Number 021324

DIRECT TELEPHONE CALLS TO:

Stephen L. Grant
330-864-5550

DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SIGNATURE(S)

1 – ∞ Dr. Frank Herzel
Inventor's signature Frank Herzel
Date Dec. 1, 2001 **Country of Citizenship** Germany
Residence Frankfurt (Oder) Germany DEX
Post Office Address Zehmeplatz 10, D-15230 Frankfurt (Oder) Germany

2 – ∞ Prof. Dr. Peter Weger
Inventor's signature [redacted]
Date Dec. 7, 2001 **Country of Citizenship** Germany
Residence Frankfurt (Oder) Germany DEX
Post Office Address Goerlitzer Strasse 22, D-15232 Frankfurt (Oder) Germany